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EL328767095US, Date of Deposit 7-3-2003

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7/3/2003  
Date

## **Failure Tolerant Passive Lubrication System**

### **Statement of Government Interest**

[0001] This invention was made under U.S. Government  
Contract N00019-02-C-3003. The Government has certain  
rights in the invention.

### **Technical Field**

[0002] This invention relates to lubrication systems  
and particularly to a lubrication system capable of  
25 supplying lubricant for a limited time following a failure  
or malfunction of a system component.

### **Background of the Invention**

[0003] Lubrication systems, such as those used in  
aircraft gas turbine engines, supply lubricant to bearings,  
gears and other engine components that require lubrication.  
The lubricant, typically oil, cools the components and  
protects them from wear. A typical oil lubrication system  
35 includes conventional components such as an oil tank, pump,  
filter and oil supply conduits.

**[0004]** If one of the lubrication system components fails, malfunctions or sustains damage, the oil supply to the lubricated component may be disrupted resulting in irreparable damage to the component and undesirable corollary consequences. For example, if an engine oil pump fails or a supply conduit develops a severe leak, the resulting loss of oil pressure could disable the engine by causing overheating and/or seizure of the bearings that support the engine rotor. An aircraft engine that becomes disabled in flight is obviously a concern, especially for a single engine military aircraft operating in hostile airspace.

**[0005]** It is known to accommodate the possibility of a failure in the oil system by configuring the system so that it continues to supply oil to the lubricated components for a limited time thereby enabling continued temporary operation of the engine. Such a system allows the aircraft crew time to safely shut down the engine or to take other appropriate actions to safeguard the aircraft and its occupants. In a military aircraft, such a system can provide the crew with valuable additional time to return to friendly airspace.

**[0006]** While it is desirable to employ a lubrication system that accommodates failure of system components, it is also highly desirable that the system be reliable and maintenance free and that it operate passively, i.e. without dedicated sensors, control systems or actuators. In an aircraft application, it is also important that the system be light weight, compact and inexpensive. For combat aircraft, it is also desirable that the system be shielded from potential battle damage.

### Summary of the Invention

[0007] It is, therefore, an object of the invention to  
5 provide a failure tolerant lubrication system for a gas  
turbine engine that operates passively to allow continued  
operation of the engine following failure of one of the  
system's conventional components and accompanying loss of  
oil pressure. It is a further object that the system be  
10 light weight, compact and inexpensive. It is a further  
object that the system be maintenance free and that it be  
shielded from damage.

[0008] According to the invention, a lubrication system  
15 for a turbine engine includes an auxiliary lubrication  
circuit featuring a reservoir of reserve lubricant and an  
aspirator to suction the reserve lubricant out of the  
reservoir. The aspirator is directly and continuously  
driven by pressurized fluid during normal operation of the  
20 engine so that it functions concurrently with the engine's  
main lubrication circuit for providing a supply of lubricant  
to a component requiring lubrication. During abnormal  
conditions, such as after a malfunction that degrades or  
disables the engine's main lubrication circuit, the  
25 auxiliary circuit continues to operate until the lubricant  
in the reservoir is depleted. The continued operation of  
the auxiliary circuit affords the engine operator an  
interval of time during which the engine can be shut down or  
other appropriate action can be taken.

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[0009] The principal advantage of the invention is that  
it operates passively, i.e. without relying on sensors,  
valves, control systems or actuators to detect the

malfunction and engage the auxiliary circuit. As a result, the system is inexpensive, reliable and substantially maintenance free. Another advantage, especially for aircraft applications, is that the system is light weight and compact. The compactness of the invention allows it to be located deep in the interior of the engine where its vulnerability to battle damage is minimized.

### **Brief Description of the Drawings**

[0010] Figure 1 is a schematic of a lubrication system according to the present invention.

[0011] Figure 2 is a cross sectional side elevation view of a physical embodiment of the lubrication system of Figure 1.

### **Best Mode for Carrying Out the Invention**

[0012] Referring to Figures 1 and 2, a gas turbine engine includes an annular flowpath 10 circumscribing an axially extending centerline or axis 12. Radially inner and outer case walls 14, 16 define radially inner and outer boundaries of the flowpath. A bearing compartment 18 defined by enclosure 20 resides radially inboard of the flowpath. A bearing 24 resides within the compartment and supports an engine rotor or shaft 26. The illustrated portion of the flowpath is a duct extending between low pressure and high pressure compressors, neither of which is illustrated. The duct carries a pressurized working medium

fluid, specifically compressed air, from the low pressure compressor to the high pressure compressor.

5       **[0013]** A buffer air supply tube **28** extends radially inwardly from just inboard of case wall **14** to a location proximate a seal **30** at the front of the bearing compartment. During engine operation, a small amount of compressed air from the flowpath enters the supply tube **28** by way of openings, not shown, in the case wall **14**. The compressed  
10       air is at a pressure slightly higher than the prevailing pressure inside the bearing compartment. The tube delivers the air to the seal **30** thus buffering the compartment, i.e. helping to resist lubricant leakage out of the bearing compartment.

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**[0014]** A lubricant reservoir **32** having a vent hole **40** is mounted inside the bearing compartment. As depicted in Fig. **2**, the wall of the reservoir is partly broken away to expose the interior of the reservoir. A lubricant supply  
20       line **34** penetrates into the reservoir. The supply line includes a check valve **36** and a restrictor **38**.

**[0015]** An aspirator, such as venturi **42**, is mounted inside the bearing compartment. A pick-up tube **44** extends  
25       from the venturi and penetrates into the reservoir. The bottom of the pick-up tube, visible in Fig. **1**, is open so that the venturi communicates with lubricant in the reservoir. A branch **46** of the buffer air supply tube extends to an intake port on the venturi, thus connecting  
30       the intake port directly to a source of pressurized air. As seen in the schematic illustration of Figure **1**, the branch of the supply tube may cross through the reservoir. An

outlet tube **48** extends from an outlet port on the venturi to a location proximate the bearing **24**.

[0016] During a normal mode of engine operation, a main  
5 lubrication circuit, not shown, provides one or more high  
pressure streams or jets of lubricant to the bearing. The  
pressure of the lubricant in the main circuit opens check  
valve **36** so that a small fraction of the main lubricant  
supply also flows through supply line **34** and discharges into  
10 the reservoir to establish a reserve quantity of lubricant  
**50** therein. The vent hole **40** allows air to escape from the  
reservoir in response to the accumulation of lubricant. The  
reserve quantity need be established only on a new or  
recently serviced engine because, as the reader will soon  
15 appreciate, the reserve quantity remains confined in the  
reservoir, although it is continuously extracted and  
replenished during normal engine operation. The restrictor  
**36** meters the quantity of lubricant flowing through line **34**  
and also introduces a pressure loss for reasons explained  
20 hereinafter.

[0017] Concurrently, a portion of the buffer air in  
supply tube **28** flows through the venturi **42** where it serves  
as a motive fluid for powering the venturi. The pressurized  
25 air flowing through the venturi acts as a power source to  
suction reserve lubricant out of the reservoir, atomize the  
lubricant into a fine mist, and propel the mist through the  
outlet tube **48**. The mist discharges from the end of tube **48**  
proximate the bearing **24**. This lubricant mist is in  
30 addition to the lubricant stream delivered by the main  
lubrication circuit. The lubricant mist is not necessary  
during normal operation because the lubricant stream  
provided by the main circuit is sufficient to lubricate and

cool the bearing. Rather, the lubricant mist is a byproduct of the auxiliary circuit.

[0018] In the event that a malfunction or failure in  
5 the main lubricant circuit disrupts the main lubricant  
stream supplying the bearing, the attendant loss of  
lubricant pressure causes closure of the check valve 36 to  
prevent the reserve lubricant from being siphoned out of the  
reservoir through supply line 34. However, because the  
10 engine is still operating, pressurized buffer air continues  
to flow through the venturi to suction reserve lubricant out  
of the reservoir and propel a lubricant mist to the bearing.  
As a result, the operation of the engine is sustained,  
albeit in an abnormal operating mode. The sustained  
15 operation of the engine ensures uninterrupted flow of  
pressurized air to power the venturi so that the engine can  
continue to be supplied with a lubricant mist and operate in  
the abnormal mode. Because the lubricant flow rate of the  
mist is much smaller than that of the lubricant stream  
20 normally provided by the main lubrication circuit, the  
bearing will likely experience highly accelerated wear and  
require replacement. Nevertheless, the lubricant mist is  
adequate to keep the engine operating safely until the  
lubricant reserve in the reservoir through supply line 34 is  
25 depleted. In one application for the invention, a reserve  
of about one-liter of lubricant can support about fifteen  
minutes of mist lubrication. The aircraft crew can take  
advantage of these additional minutes of operation to  
systematically follow the procedures necessary to safeguard  
30 the aircraft and its occupants and to safely shut the engine  
down before the rotor seizes or overheats. If the engine  
powers a military aircraft operating in hostile airspace,

the crew can use the interval of extended operation to proceed toward friendly airspace.

[0019] In view of the foregoing, certain additional features and many advantages of the invention can now be appreciated. The lubricant supply line **34** can cross through the reserve lubricant **50** in the reservoir as shown in Figure **1**. The reserve lubricant then serves as a heat sink to lower the temperature of the hot, pressurized buffer air before that air enters the venturi. Cooler air may be beneficial because the fine lubricant droplets created in the venturi will acquire heat readily from the buffer air. This heat transfer promotes the formation of coke, which is an undesirable hydrocarbon deposit, in the venturi **42** and outlet tube **48** during the normal mode of operation. The reserve lubricant in the reservoir is not similarly affected because its greater bulk resists rapid heat transfer. The cooler air also guards against ignition of the lubricant.

[0020] The vent hole **40**, in addition to allowing air to escape during filling of the reservoir, also allows air to enter the reservoir as lubricant is being extracted during the abnormal mode of operation. This prevents the establishment of a vacuum in the reservoir that could open the check valve **36**.

[0021] The restrictor **36** in the supply line **34** not only meters the lubricant flow into the reservoir, but also introduces a pressure loss. If the restrictor were absent, the high pressure of the main lubricant circuit would urge lubricant through the reservoir **32**, the venturi **42** and the outlet tube **48** at a high rate during normal operation, with the result that an adequate reserve of lubricant might not



accumulate in the reservoir. By contrast, the lower reservoir pressure resulting from the presence of the restrictor ensures that lubricant outflow from the reservoir is governed by the action of the venturi, which extracts  
5 lubricant at a more modest rate, thus promoting the establishment of the reserve and ensuring its continued presence.

**[0022]** The pressurized buffer air flows exclusively  
10 through the venturi rather than entering the reservoir to pressurize the lubricant therein. The absence of high pressure in the reservoir, which results from this absence of pressurized air in the reservoir and also from the restrictor **38** in the lubricant supply line, minimizes  
15 structural demands on the reservoir. As a result, the reservoir is light weight and compact, both of which are significant advantages in aircraft applications. The absence of high pressure acting on the reserve lubricant also conserves lubricant during operation in the abnormal  
20 mode.

**[0023]** The compact, light weight character of the reservoir allows it to reside radially inboard of the engine flowpath **10**. Such location is advantageous in a military  
25 aircraft because it shields the reservoir from battle damage. Indeed, the reservoir **32**, venturi **42** and outlet tube **48** are compact enough to fit within the bearing compartment **18**, where they are afforded even more protection from damage.

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**[0024]** As already pointed out, the venturi is connected directly to a source of pressurized motive fluid, specifically compressed air extracted from the flowpath **10**

by way of openings in radially inner flowpath wall **14**. The connection is referred to as a direct connection because the air flows from the flowpath to the venturi without interruption or without being diverted to other uses prior to entering the venturi. As a result, the useful properties of the pressurized air entering the venturi are unimpaired. For example, because the air suffers no appreciable pressure loss, as might occur if the air had been used for some other purpose prior to entering the venturi, the source air can be of relatively low pressure. This is an advantage because the extraction of low pressure air causes a smaller loss of engine efficiency than does the extraction of higher pressure air. In addition, this low pressure air is relatively low in temperature so that it requires no cooling (Fig. **2**) or requires no more cooling than can be accomplished by using the reserve oil as a heat sink (Fig. **1**). Moreover, air extracted from the radially innermost extremity of the flowpath is substantially free of dirt and other particulate contaminants because the action of the low pressure compressor tends to centrifuge such contaminants radially outwardly, away from the inner wall **14**. Because of the direct path to the venturi, this clean air is likely to remain clean rather than picking up contaminants that might be harmful to the bearing **24** or to components of the lubrication system.

**[0025]** The system operates without any dedicated valves, actuators or controllers. In particular, the buffer air supply tube **28** passively communicates with both the source of pressurized motive fluid (i.e. with the flowpath **10**) and with the venturi **42** during both the normal and abnormal modes of operation. Therefore, the system is highly reliable and maintenance free. In addition, because

lubricant continually flows into and out of the reservoir during the normal mode of operation, the reserve lubricant is continually refreshed. As a result, the reserve lubricant resists age related degradation that might afflict  
5 a stagnant stockpile of reserve lubricant.

[0026] During the normal mode of operation, the auxiliary circuit operates concurrently with the main lubrication circuit. The main circuit provides a normal  
10 quantity of lubricant to the bearing in the form of a high pressure stream or jet. The reservoir of the auxiliary circuit concurrently receives a fractional quantity of lubricant. The venturi suctions reserve lubricant from the reservoir and delivers an auxiliary quantity of lubricant to  
15 the bearing in the form of a mist. In combination, the normal quantity of lubricant provided by the main circuit and the auxiliary quantity provided by the auxiliary circuit represent a normal aggregate quantity of lubricant delivered to the bearing.

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[0027] In the abnormal mode of operation, the main circuit's capability for providing lubricant has become either degraded or, in the limit, completely disabled. Either way, the main circuit delivers a diminished quantity  
25 of lubricant to the bearing and provides a diminished fractional quantity of lubricant to the reservoir. In the case of a degraded system, the diminished quantity and the diminished fractional quantities are finite amounts. In the case of a disabled system, the diminished quantity and  
30 diminished fractional quantities are zero or essentially zero. However the venturi continues to suction reserve lubricant from the reservoir and delivers the auxiliary quantity of lubricant to the bearing in the form of a mist.

In combination, the diminished quantity of lubricant provided by the main circuit and the auxiliary amount provided by the auxiliary circuit represent a diminished aggregate quantity of lubricant delivered to the bearing.

5 If the main lubrication circuit is degraded, there may be sufficient lubricant pressure to hold check valve **36** at least partially open thereby replenishing at least some of the reserve lubricant in the reservoir **32**. If the main lubrication circuit is completely disabled, the valve **36**

10 closes, however the venturi continues to provide an auxiliary lubricant mist for a limited time, until the reserve lubricant is depleted from the reservoir.

**[0028]** Although this invention has been shown and

15 described with reference to a detailed embodiment thereof, it will be understood by those skilled in the art that various changes in form and detail may be made without departing from the invention as set forth in the accompanying claims.

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**[0029]** I claim: